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Accelerated Abrasion Tests Of Polymeric Protective Coatings For Corrugated Metal Pipe

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16. ABSTRACT

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It is concluded that polymeric coatings complying with M246 do not necessarily possess abrasion resistance equal to that of hot-dipped asphalt coatings complying with M190. It is recommended that any future abrasion studies of these products be conducted with pilot installations where abrasive flow is considered relatively severe. While the accelerated laboratory tests are good indicators of relative abrasion resistance, they do not consider conditions such as contamination of the coatings in production, damage to the coatings in shipment and placement, and aging of the coating.

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Abrasion resistant coatings, abrasion test, accelerated testing, coatings, corrugated metal pipe, polymers

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STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF STRUCTURES & ENGINEERING SERVICES
OFFICE OF TRANSPORTATION LABORATORY

January 1977

TL No. 646738

Mr. C. E. Forbes
Chief Engineer

Dear Sir:

I have approved and now submit for your information this final research project report titled:

ACCELERATED ABRASION TESTS OF POLYMERIC PROTECTIVE COATINGS FOR CORRUGATED METAL PIPE

Study made by . . . . Structural Materials Branch

Under the Supervision of . . . . Eric F. Nordlin, P. E.

Principal Investigator . . . . J. Robert Stoker, P. E.

Co-Investigator . . . . William F. Crozier, P. E.

Report Prepared by . . . . William F. Crozier, P. E.

Very truly yours,

George A Hill

GEORGE A. HILL
Chief, Office of Transportation Laboratory

WFC:bjs
Attachment

ACKNOWLEDGEMENTS

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I. INTRODUCTION

Historically, the most common supplementary coating used to protect corrugated metal pipe (CMP) from adverse environments has been hot applied asphalt. A minimum of 0.050 inch of asphalt is typically applied to the fabricated CMP through a process known as hot-dipping. If the asphalt coating is damaged during shipment or placement, repairs are normally made by applying cold asphalt mastic.

In recent years, due largely to shortages of petroleum products and increasingly stringent air pollution controls, several companies have attempted to develop alternate coatings which would perform at least as well as hot-dipped asphalt. In 1972, the California Department of Transportation (Caltrans) initiated a laboratory evaluation of the new coatings to assess their performance relative to the traditional asphalt coatings. The results of that evaluation, documented in Reference 1, indicated that polymeric coatings could provide adequate corrosion resistance, but were inconclusive with regard to the ultimate abrasion resistance under conditions simulating the interior of a CMP.

Since that time, the American Association of State Highway and Transportation Officials (AASHTO) has developed a new specification, Designation: M246-76I, pertaining to polymeric coatings(2). At least two products, which are intended for compliance with M246-76I, are currently available:

- Nexon, a thermoplastic coal tar based resin marketed by the United States Steel Corporation

- Plasticote, a polyvinyl chloride coating marketed by Wheeling-Pittsburg Steel Corporation.

Both of these products are applied to one or both sides of the flat galvanized steel sheet prior to fabrication of the CMP.

The primary objective of this research project was to compare the ultimate abrasion resistance of these two polymeric coatings with that of hot-dipped asphalt coatings. This report presents the results of a total of 30 accelerated abrasion tests (including those described in Reference 1) simulating flow inside a CMP.

II. CONCLUSIONS AND RECOMMENDATIONS

Based on the findings presented herein and in Reference 1, polymeric coatings complying with AASHTO Designation: M246-76I possess corrosion resistance equal to or better than hot-dipped asphalt coatings, but do not necessarily possess equal resistance to abrasive flow. These findings have been implemented by Caltrans via a standard special provision which allows the use of polymeric coatings as an alternate to hot-dipped asphalt coatings on the backfill side of CMP or on the inside of CMP where the flow is considered non-abrasive. To date, there are no known installations of these polymeric coatings on Caltrans contracts to complement these conclusions.

Since laboratory abrasion tests cannot fully duplicate actual field conditions, it is recommended that any future abrasion studies of these products be conducted with pilot installations where abrasive flow is considered relatively severe. Such studies could include the effects of contamination of the coatings in production, damage to the coatings in shipment and placement, and aging of the coatings.

III. TECHNICAL DISCUSSION

A. Description of Coating Samples

All abrasion test specimens were cut from samples of 16 gage (0.06") CMP with a nominal diameter of 18 inches and 2 2/3 inches by 1/2 inch helical corrugations. All the samples had been galvanized prior to applying the protective coatings. In order to maintain their identity, the various samples were assigned coded numbers as described below.

The most commonly used protective coating for CMP is asphalt applied in accordance with AASHTO Designation: M190. The fabricated pipe is dipped in hot asphalt to obtain a minimum thickness of 0.050 inches. Asphalt coating samples were obtained on three occasions:

- Sample A-1 was a full section of hot-dipped pipe which had aged above ground for perhaps five years. All the abrasion test specimens described in Reference 1 (identified as Runs 1 through 4 in this report) were taken from this sample.

- Sample A-2 was taken from a full section of pipe before it had been hot-dipped. The abrasion test specimens, after being cut to exact size, were individually hot-dipped at a commercial facility and included in Runs 5 through 8.

- Sample A-3 was prepared in the same manner as Sample A-2, and the specimens were included in Runs 9 and 10.

Nexon is a thermoplastic coal tar based resin which is applied to the flat galvanized steel sheet prior to fabrication of the CMP. The United States Steel Corporation provided samples of coated corrugated sections on three occasions:

- Sample N-1 was a finished section of pipe with a 0.020 inch coating of Nexon on the inside. All the abrasion test specimens described in Reference 1 (identified as Runs 1 through 4 in this report) were taken from this sample.

- Sample N-2 consisted of two sections of pipe with interior Nexon coatings of 0.010 inches and 0.020 inches. Specimens from this sample were included in Runs 5 through 8. After reviewing the test results and performing additional tests of their own, U. S. Steel felt that the N-2 sample was not representative of their normal production runs.

- Sample N-3 consisted of two additional sections of pipe to replace Sample N-2.

Plasticote is polyvinyl chloride coating supplied by the Wheeling-Pittsburg Steel Corporation. Like Nexon, it is applied to the flat galvanized steel sheet prior to fabrication of the CMP.

- Sample P-1 was a finished section of pipe with a 0.010 inch interior Plasticote coating provided by Wheeling-Pittsburg Steel.

- Sample P-2 consisted of two sections of pipe with interior Plasticote coatings of 0.003 inches and 0.010 inches. The coating had been applied by California Finished Metals, Inc., and the pipe had been fabricated by Pacific Corrugated Pipe Company.

During the course of this testing program, the AASHTO specification for the polymeric coatings was being developed by AASHTO and the coating manufacturers. Only the final set of polymeric coating samples, N-3, P-1, and P-2 were tested for compliance with AASHTO Designation: M246-76I(2). Although all the required tests could not be performed because appropriate test apparatus was not available, the test results summarized in Figure 1, indicated that the samples N-3, P-1, and P-2 substantially complied with M246-76I.

Valid AASHTO tests for holidays (pinholes) could not be performed because large, flat sheets of the polymeric coatings were not available. However, tests of the corrugated samples using an Elcometer Portector 169 (67.5 volts) holiday detector indicated the presence of holidays in the N-3 and P-1 samples and a high frequency of holidays in the P-2 sample.

FIGURE 1, SUMMARY OF AASHTO M246 TESTS

AASHTO Test	0.020" Nexon N-3	0.010" Nexon N-3	0.010" Plasticote P-1	0.003" Plasticote P-2	0.010" Plasticote P-2
Adhesion: 180°,0.5" dia.					
@ 0°F	Pass	Pass	Marginal		Pass
@77°F	Pass	Pass	Pass		Pass
@120°F	Pass	Pass	Pass		Pass
Impact: Gardner 5/8" punch @77°F					
@ 35 in-lb	Pass	Pass	Pass		Pass
@160 in-lbs*	Pass	Pass	Pass		Pass
Imperviousness: 48 hrs.					
NaCl	Pass	Pass	Pass		Pass
NaOH	Pass	Pass	Pass		Pass
H_2SO_4	Pass	Pass	Pass		Pass**
Freeze-Thaw: 100 cycles	Pass	Pass	Pass	Pass	
Weatherability:					
Weatherometer,1000 hrs.	Pass	Pass	Pass	Pass	Pass

*Not required by AASHTO

**Some delamination at a pinhole

B. Abrasion Test Procedures

All abrasion test specimens were dimensioned as shown in Figure 2 and numbered consecutively as described in Section III.C. For samples A-2 and A-3 the specimens were cut from the CMP prior to applying the asphalt coating. For all other samples, the specimens were cut from the coated CMP. Because some of the samples had been damaged in shipment, care was taken to avoid cutting specimens from areas where the coatings appeared to be damaged. Special care was also required to avoid damaging the polymeric coatings during the flame cutting, sawing, and drilling procedures.

With the exception of specimens 1 and 2, twelve thickness measurement locations were marked on the outside (away from the flow) of each specimen as shown in Figure 2. The thickness measurement locations for specimens 1 and 2 were similar and are detailed in Reference 1. For abrasion test Runs 1 through 8, thicknesses were measured by a spring-loaded dial gage mounted on an aluminum "C"-frame shown in Figure 3. For Runs 9 and 10, thicknesses were measured by an Accuderm, Model 5-A, magnetic thickness gage.

After recording initial thickness measurements, specimens were mounted in each of the four quadrants of the abrasion testing machine shown in Figure 4 and detailed in Figure 5. In many cases the forward and aft edges of the specimens were bent slightly to conform to the inside of the testing machine to minimize the flow of material behind the specimens. The V-belt which drove the rotating drum was placed in the appropriate size pulleys such that the peripheral speed of the drum at the location of the specimens was typically five feet per second.

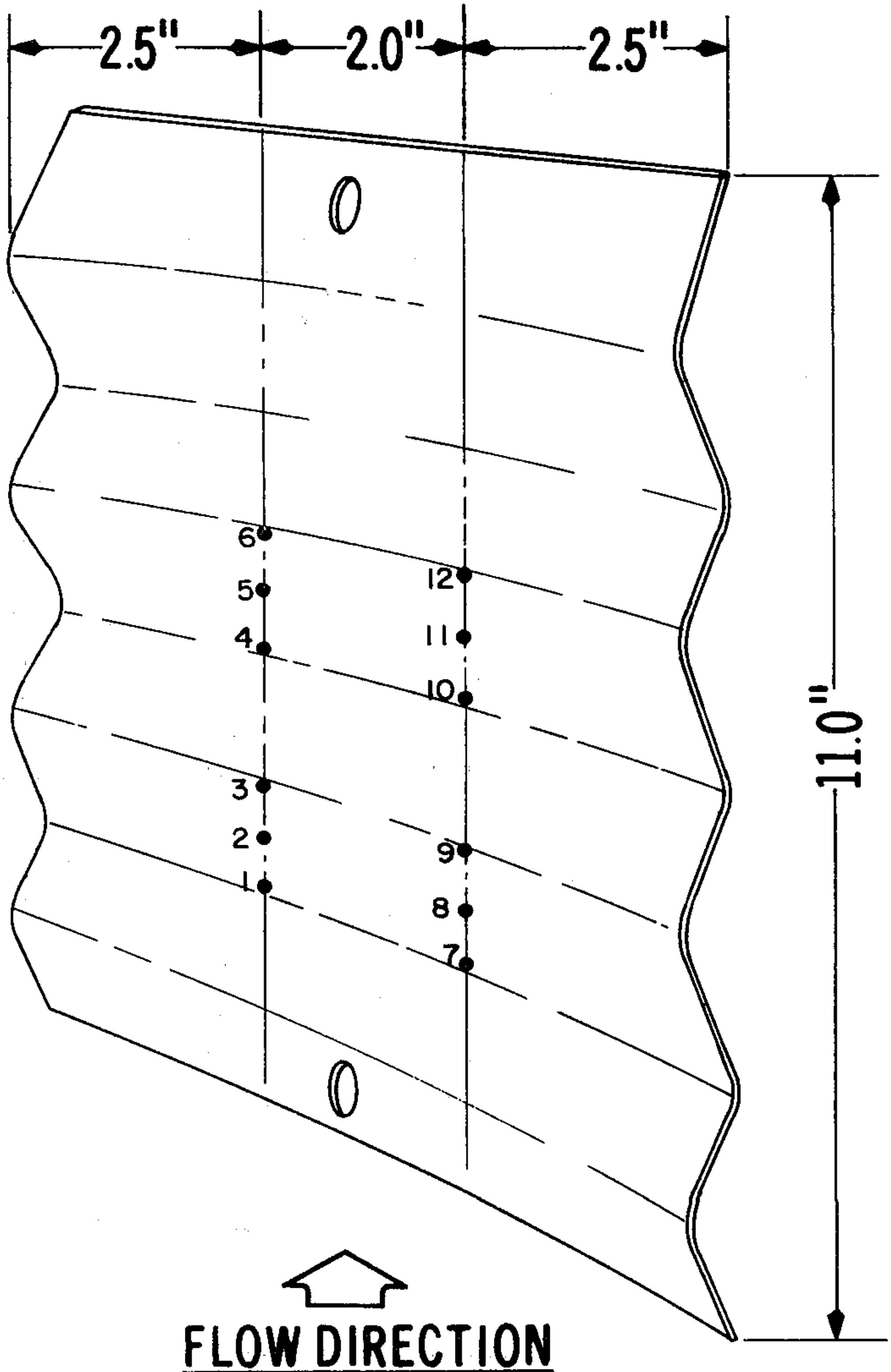


FIGURE 2

Abrasion Test Specimen And Thickness Measurement Locations

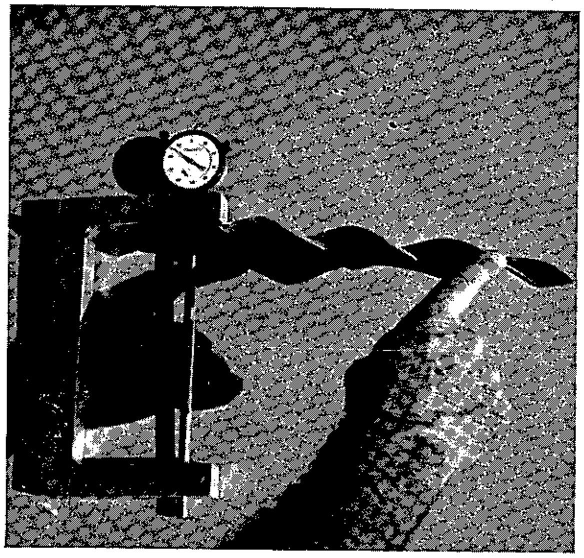


FIGURE 3, TYPICAL METHOD FOR MEASURING
MEASURING COATING THICKNESS

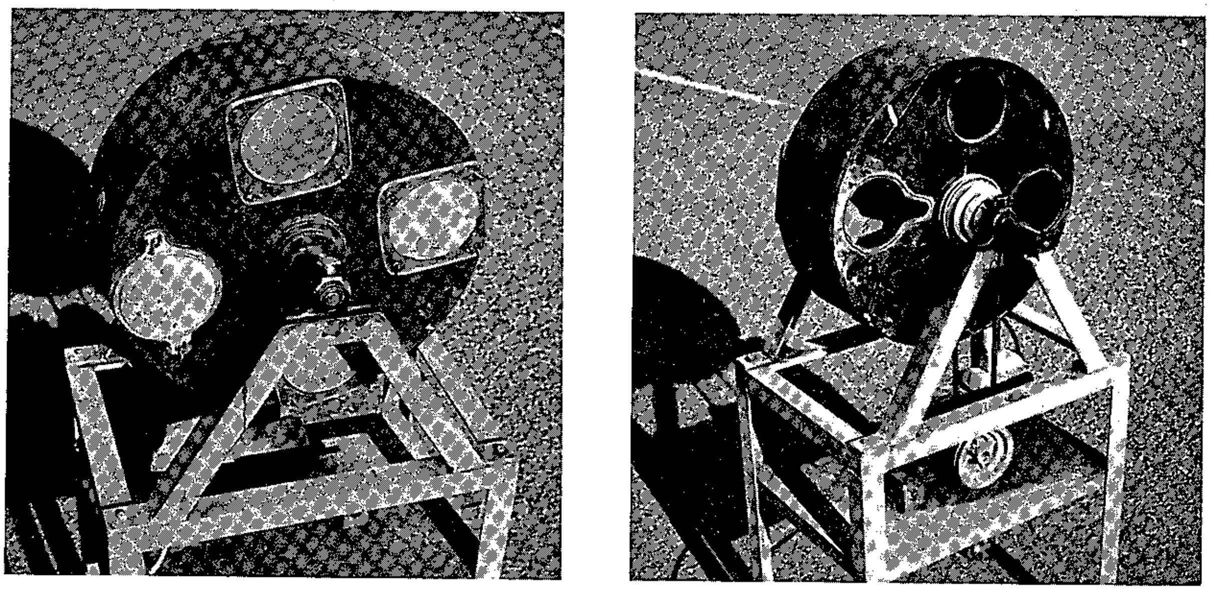


FIGURE 4, ABRASION TESTING MACHINE

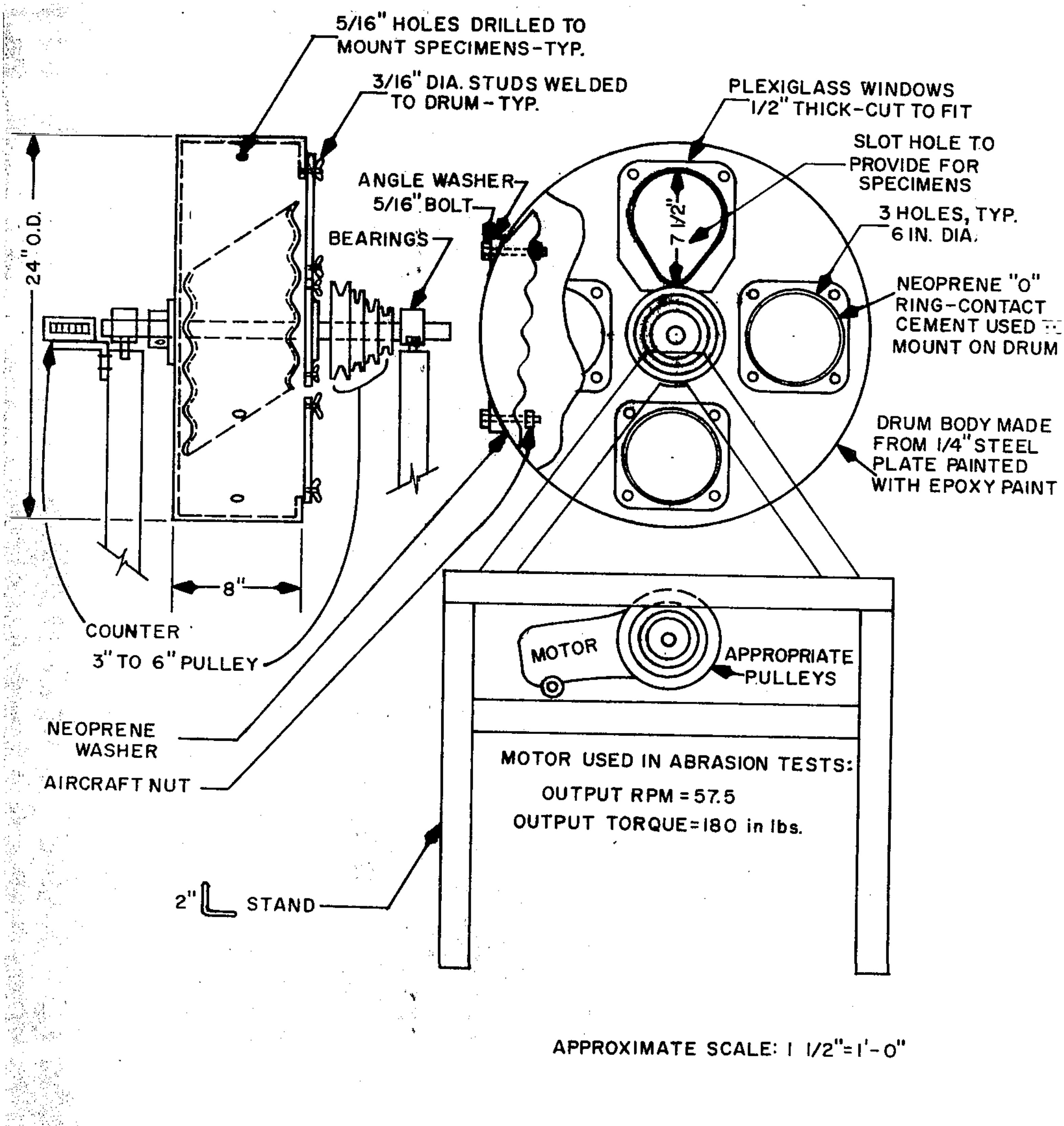


FIGURE 5 ABRASION TESTING MACHINE DETAIL

For Run 1 the drum was charged with 59 pounds of water and 7 pounds of 3/8 inch by 1/2 inch Fair Oaks river-run aggregate, coded C-1. The test conditions for this single course aggregate test run were chosen to simulate the most severe abrasion conditions used by the Bureau of Reclamation(3).

For all subsequent runs the drum was charged with 35 pounds of water and 7 pounds of fine aggregate from California's Bear River which is considered one of the sources of California's hardest aggregates. For Runs 2, 3, and 4 the fine aggregate gradation, coded F-1, complied with Section 90-3.03 of the Standard Specifications(4). For Runs 5 and 6, a similar, but more specific, gradation, coded F-2, was used in the interest of closer control over the gradation parameter. During the course of Runs 5 and 6, it appeared that the finest particles were suspended in the water and were not contributing to the abrasion process. These fine particles were, therefore, removed from the fine aggregate for Runs 7, 9, and 10 yielding the gradation coded F-3. The specific gradations used were as follows (percent by weight):

Sieve Size Pass X Retain	F-2 Percent	F-3 Percent
4 x 8	10	13
8 x 16	7	10
16 x 30	14	16
30 x 50	49	61
50 x 100	19	0
100 x 200	1	0
200 x ---	0	0
Total	100	100

The abrasion test runs were stopped at various intervals (described in Section III.C. of this report) to measure the progressive loss of coating thickness and/or check for signs of failure such as delamination or perforation of the coatings. Whenever the coating thicknesses were measured, all aggregate and water was removed from the drum, and the drum and specimens were thoroughly rinsed. After taking thickness measurements and remounting the specimens, the drum was recharged with agregate and water but the method of recharging was not the same for all test runs. For Runs 1 through 5 the aggregate which had been scooped out of the drum was simply returned to the drum and a fresh charge of water was added. Because much of the fine aggregate was suspended in the water during the abrasion process, a substantial amount of aggregate was lost using this recharging procedure - e.g., at the end of Run 5, only 3 pounds of the original 7 pounds of aggregate remained in the drum. In the interest of accelerating the abrasion rate, the recharging procedure was modified for Runs 6 through 10. For these latter runs, fresh aggregate was added to the remaining aggregate such that the total aggregate recharge was 7 pounds.

Most test runs were performed indoors at a room temperature of 70°F to 75°F. Thermometer measurements indicated that the water temperature was 10°F to 15°F higher than ambient temperature due to the abrasion process and heat from the electric motor. Higher temperatures were achieved by performing the tests outdoors during summer months, and lower temperatures were achieved by placing the rotating drum inside an environmental chamber.

The data reduction method was the same as that described in Reference 1. In order to condense the data from each of the 12 measurement locations (Figure 2) into a more useful form, an Abrasion Index was calculated to represent the maximum wear

TRANSPORTATION LABORATORY
STRUCTURAL MATERIALS RESEARCH UNIT

ABRASION TEST OF COATED CMP

COATING TYPE: 20 mil Nexon

MANUFACTURER: U.S.S.

SHEET 5 of 7
DATE May, 1974
Specimen Bx (#12)
S.M. No. 74-491
Tested By VMC

LOCATION №	THICKNESS MEASUREMENTS, inches (incl. steel sheet)						
	0 ~	150 K~	300 K~	450 K~	600 K~	750 K~	900 K~
		300 K~ = 300,000 revolutions.	Change in thickness (mils)				
1	.074	.073^{-1}	.073^{-1}	.073^{-1}	.072^{-2}	.071^{-3}	.071^{-3}
2	.076	.075^{-1}	.0745^{-1}	.073^{-3}	.072^{-4}	.070^{-6}	.068^{-8}
3	.073	.073^{0}	.071^{-2}	.073^{0}	.072^{-1}	.070^{-3}	.071^{-2}
4	.0745	.075^{0}	.075^{0}	.074^{0}	.0745^{0}	.074^{0}	.074^{0}
5	.075	.074^{-1}	.073^{-2}	.074^{-1}	.073^{-2}	.072^{-3}	.071^{-4}
6	.075	.075^{0}	.074^{-1}	.074^{-1}	.074^{-1}	.075^{0}	.074^{-1}
7	.074	.075^{+1}	.074^{0}	.074^{0}	.074^{0}	.073^{-1}	.073^{-1}
8	.076	.075^{-1}	.074^{-2}	.073^{-3}	.072^{-4}	.071^{-5}	.070^{-6}
9	.074	.073^{-1}	.0725^{-1}	.072^{-2}	.072^{-2}	.072^{-2}	.071^{-3}
10	.075	.075^{0}	.0745^{-1}	.075^{0}	.074^{-1}	.074^{-1}	.07[illegible]$^{-1}$
11	.078	.077^{-1}	.076^{-2}	.076^{-2}	.075^{-3}	.073^{-5}	.073^{-5}
12	.075	.074^{-1}	.076^{+1}	.074^{-1}	.073^{-2}	.075^{0}	.075^{0}
AI		-1.00	-2.00	-2.25	-3.25	-4.75	-5.75

FIGURE 6, TYPICAL DATA SHEET

of the coating. The 12 measurement locations consist of four zones of three points each. In other words, measurement locations No. 1, No. 2, and No. 3 make up the first zone. The Abrasion Index is the average of the maximum wear reading from each zone. To illustrate this computation, Figure 6 represents a typical data sheet. The Abrasion Index for this 20 mil Nexon specimen after 600,000 revolutions was:

$$AI = \frac{-4-2-4-3}{4} = \frac{-13}{4} = -3.25 \text{ mils}$$

The Abrasion Rates were calculated by dividing the Abrasion Index by the cumulative number of revolutions of the drum.

C. Abrasion Test Results

Figure 7 summarizes the test conditions and results of each abrasion test run. Although each run included four specimens, some specimens are not listed in Figure 7 because they were not within the scope of this research project. The column titled "Cycles to Failure" indicates the number of cycles when perforation of the coating was first detected. For those coatings which were never perforated throughout the duration of a test run, the "Cycles without Failure" are listed in the adjacent column.

Run 1 was the only run which employed course aggregate, and was terminated after 170,000 cycles when the asphalt specimen began to fail. The 0.020 inch thick Nexon specimen did not fail, and exhibited an abrasion rate of about 1/40th of that of the asphalt. Under the heavy impacts of the course aggregate, the asphalt was kneaded rather than abraded. If this type of course aggregate flow was expected in a CMP installation, the

FIGURE 7, SUMMARY OF ABRASION TESTS

Run #	Sample #	Specimen #	Coating Thickness, inches	Asphalt Condition	Gradation (1)	Water Temp °F (2)	Abrasion Rate, inches per million Cycles	Cycles to Failure millions	Cycles without Failure millions
1	N-1	1	0.020		C-1	85	0.003(3)		0.17
1	A-1	2	0.050	Aged	C-1	85	0.118	0.17	
2	N-1	3	0.020		F-1	85	0.013		0.50
2	A-1	4	0.050	Aged	F-1	85	0.019		0.50
3	N-1	5	0.020		F-1	85	0.007		0.50
3	A-1	6	0.050	Aged	F-1	85	0.025		0.50
4	N-1	7	0.020		F-1	85	0.012		0.50
4	A-1	8	0.050	Aged	F-1	85	0.029		0.50
5	N-2	9	0.020		F-2	105	0.005	0.60	
5	N-2	10	0.010		F-2	105	0.005	0.75	
5	A-2	11	0.050	New	F-2	105	0.008		0.75
6	N-2	12	0.020		F-2	85	0.005	0.90	
6	N-2	13	0.010		F-2	85	0.005	0.75	
6	A-2	14	0.050	New	F-2	85	0.006		0.90
6	A-2	11(4)	0.050	New	F-2	85	0.008		1.65
7	N-2	15	0.020		F-3	57	0.005	1.20	
7	N-2	16	0.010		F-3	57	0.005	1.20	
7	A-2	17	0.050	New	F-3	57	0.010		1.20
7	A-2	14(4)	0.050	New	F-3	57	0.012		2.10
8	N-2	18	0.020		None	50	0		2.20
8	N-2	19	0.010		None	50	0		2.20
8	A-2	20	0.050	New	None	50	0		2.20
9	N-3	21	0.020		F-3	85	0.002	2.00	
9	N-3	22	0.010		F-3	85	0.002	2.00	
9	P-1	23	0.010		F-3	85	0.001	2.00	
9	A-3	24	0.050	New	F-3	85	0.006		2.00
10	N-3	25	0.010		F-3	85	0.002	1.48	
10	P-2	26	0.010		F-3	85	0.003	0.64	
10	P-2	27	0.003		F-3	85	0.002	0.64	
10	A-3	24(4)	0.050	New	F-3	85	0.006		3.80

(1) Each run included 7 pounds of aggregate except for Run 8 which included no aggregate.

(2) Each run included 35 pounds of water flowing at 5.00 feet per second except for Run 1 which included 59 pounds of water flowing at 3.65 feet per second.

(3) Thickness measurement locations were atypical for Run 1 (1).

(4) Same specimen from previous test run.

invert would normally be paved. It was, therefore, decided that a fine aggregate flow would be more appropriate for evaluating the abrasion resistance of the polymeric coatings.

Runs 2, 3, and 4 simulated fine aggregate flow in a CMP and were intended to compare the abrasion rates of Nexon and asphalt. All were run 500,000 cycles under nominally identical conditions and the resulting abrasion rates were reasonably consistent. Averaging the results of the three runs indicated that the asphalt abraded at a rate of about 2.2 times that of Nexon(1). Similar abrasion testing by Southwest Research Institute (SwRI) indicated that the asphalt abraded at a rate of three to four times that of Nexon(5). Unfortunately, neither Runs 2, 3, and 4 nor the SwRI tests were continued such that the ultimate abrasion resistance of the two coatings could be compared.

Runs 5, 6, and 7 were intended to measure the relative ultimate abrasion characteristics of Nexon versus asphalt by running the tests until coating failure. Secondary objectives were to gain additional abrasion rate data and to assess the effect of temperature variations. Thickness measurements were made at more frequent intervals and the detailed test results of each run are presented in Figures 8, 9, and 10.

In all cases the Nexon failure occurred between measurement locations No. 2 and No. 3, near the peak of a corrugation on the upstream side. This failure location is similar to that described by SwRI(5). In each case the failure was preceded by blistering of the coating and the wear rate did not appear to be linear in the failure area -- i.e., the coating had actually worn only a few mils when it failed suddenly.

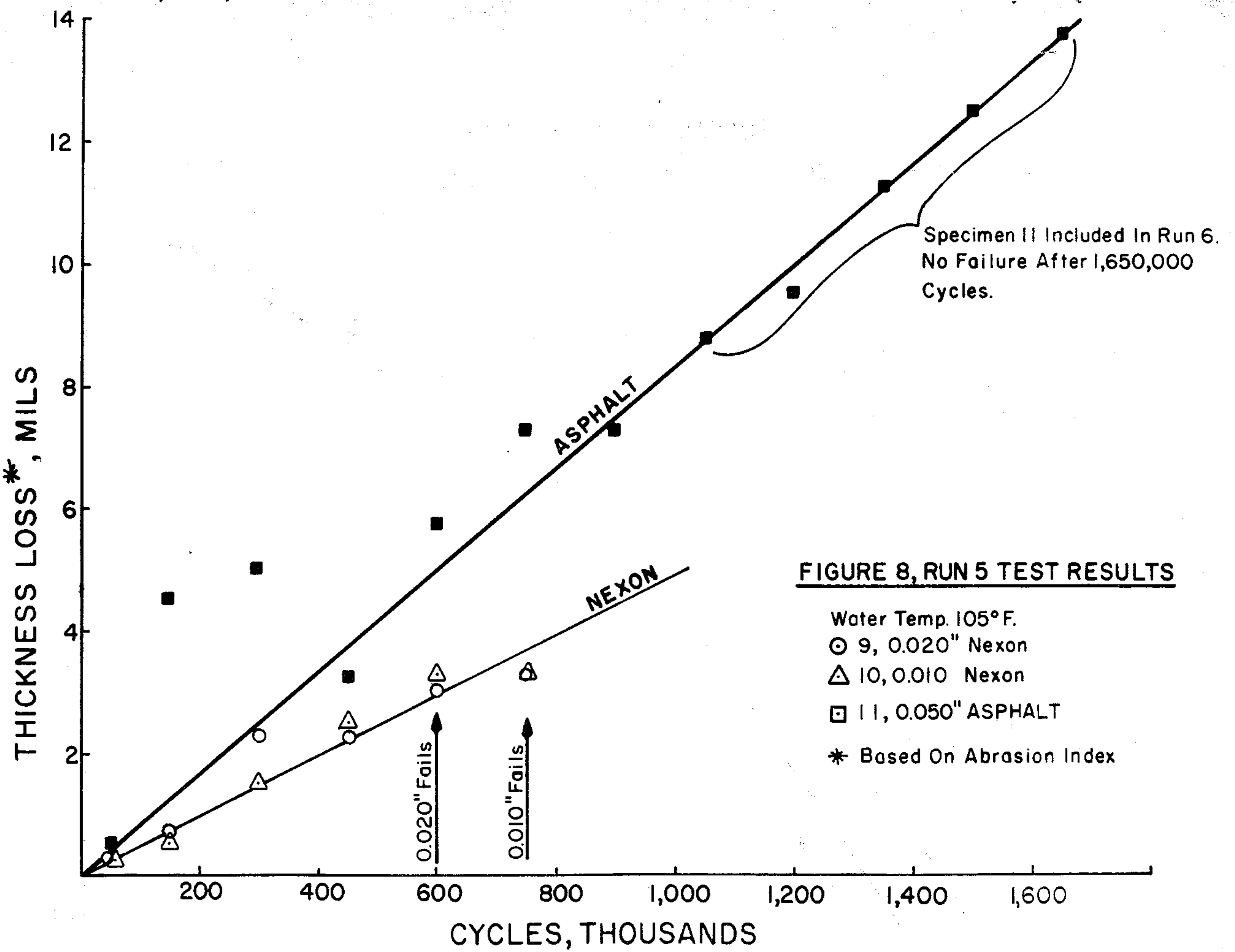


FIGURE 8, RUN 5 TEST RESULTS
Water Temp. 105° F.
9, 0.020" Nexon
10, 0.010 Nexon
11, 0.050" ASPHALT
* Based On Abrasion Index
Specimen 11 Included In Run 6. No Failure After 1,650,000 Cycles.
ASPHALT
NEXON
0.020" Fails
0.010" Fails
THICKNESS LOSS*, MILS
CYCLES, THOUSANDS
14
12
10
8
6
4
2
200
400
600
800
1,000
1,200
1,400
1,600

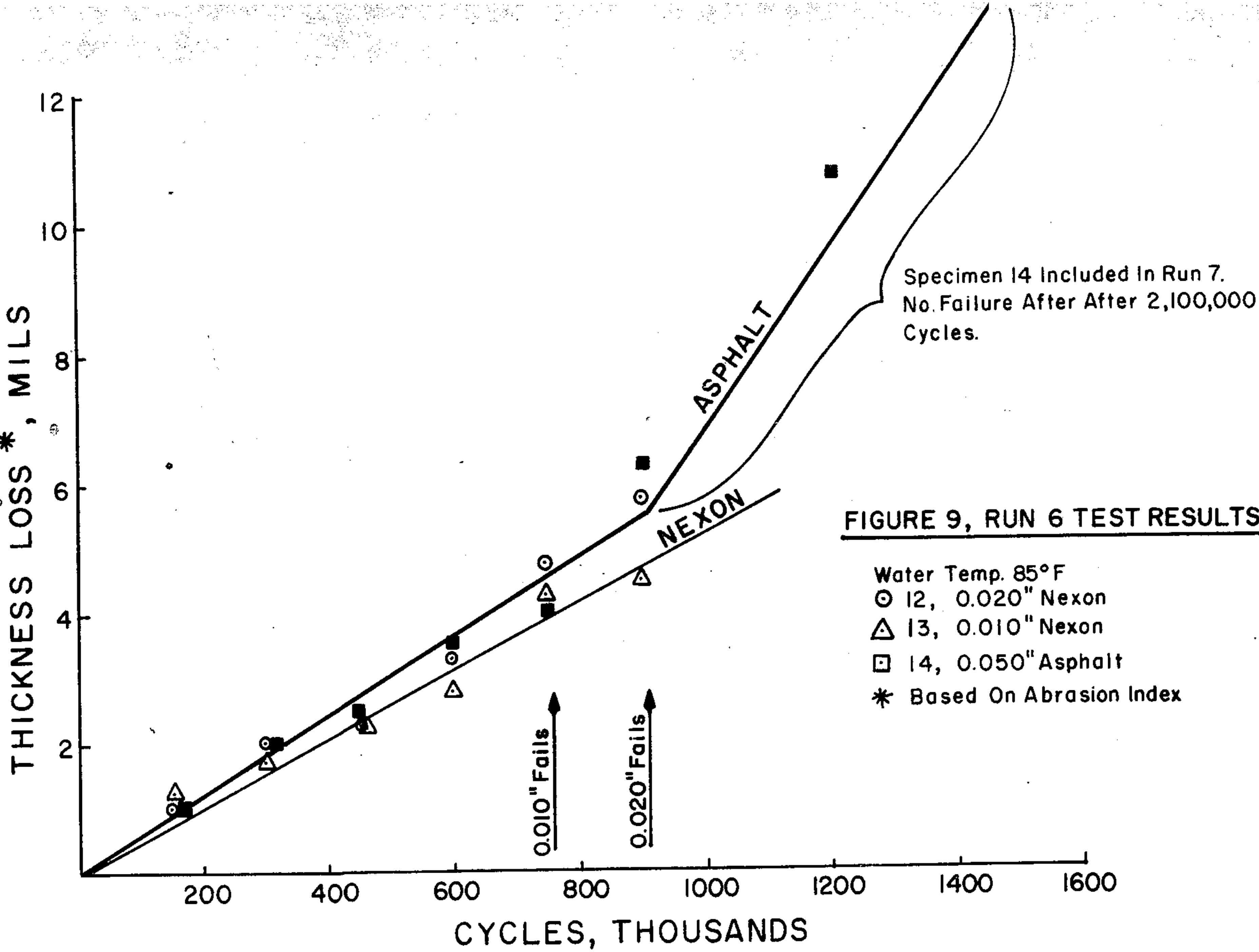


FIGURE 9, RUN 6 TEST RESULTS

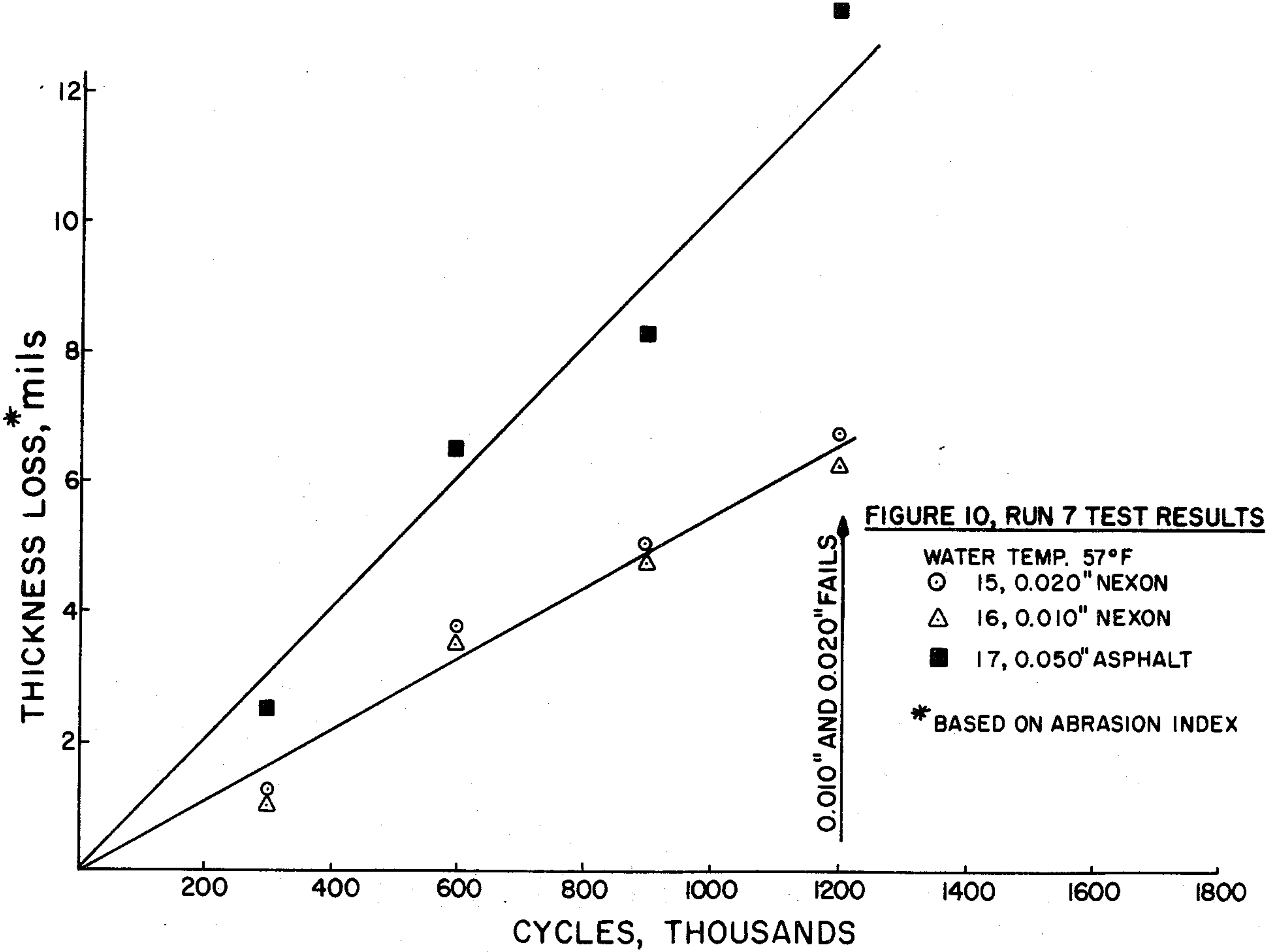


FIGURE 10, RUN 7 TEST RESULTS

Figure 11 presents the abrasion rate data from the three test runs versus water temperature to illustrate the abrasion rate's dependency upon temperature. Although the data is very limited, it indicates that the abrasion rate of both coating types tends to increase as the temperature is decreased. This corroborates the findings of SwRI(5).

Figure 12 presents the number of cycles to failure of the Nexon coating versus water temperature. This data indicates that a longer lifetime would be anticipated at lower temperatures, but the anticipated lifetime of the Nexon coatings is less than that of the asphalt coatings regardless of temperature. Of the six Nexon specimens tested, the longest lifetime realized was 1,200,000 cycles. The three asphalt specimens, 11, 14, and 17, withstood 1,650,000, 2,100,000, and 1,200,000 cycles respectively without any signs of failure.

At first glance, there appears to be a conflict between the data presented in Figure 11 versus that of Figure 12, i.e. - Figure 11 indicates that the Nexon abrades faster at lower temperatures while Figure 12 indicates that the number of cycles to failure of the Nexon is higher at lower temperatures. This apparent conflict is due to the fact that the failure mode was not what would be normally expected in an abrasion test. Normally one would expect the coating thickness to abrade in a linear fashion until there was no coating left .. thus constituting failure. In these tests the Nexon abraded linearly until the coating blistered. Once the coating had blistered, it did not take long for the abrasive flow to destroy the blistered coating. The initiating mode of failure was, therefore, the blistering of the coating, not linear abrasion as we would normally anticipate. The results indicate that the Nexon coatings are more resistant to blistering at lower temperatures and their anticipated lifetimes are, therefore, longer at lower temperatures.

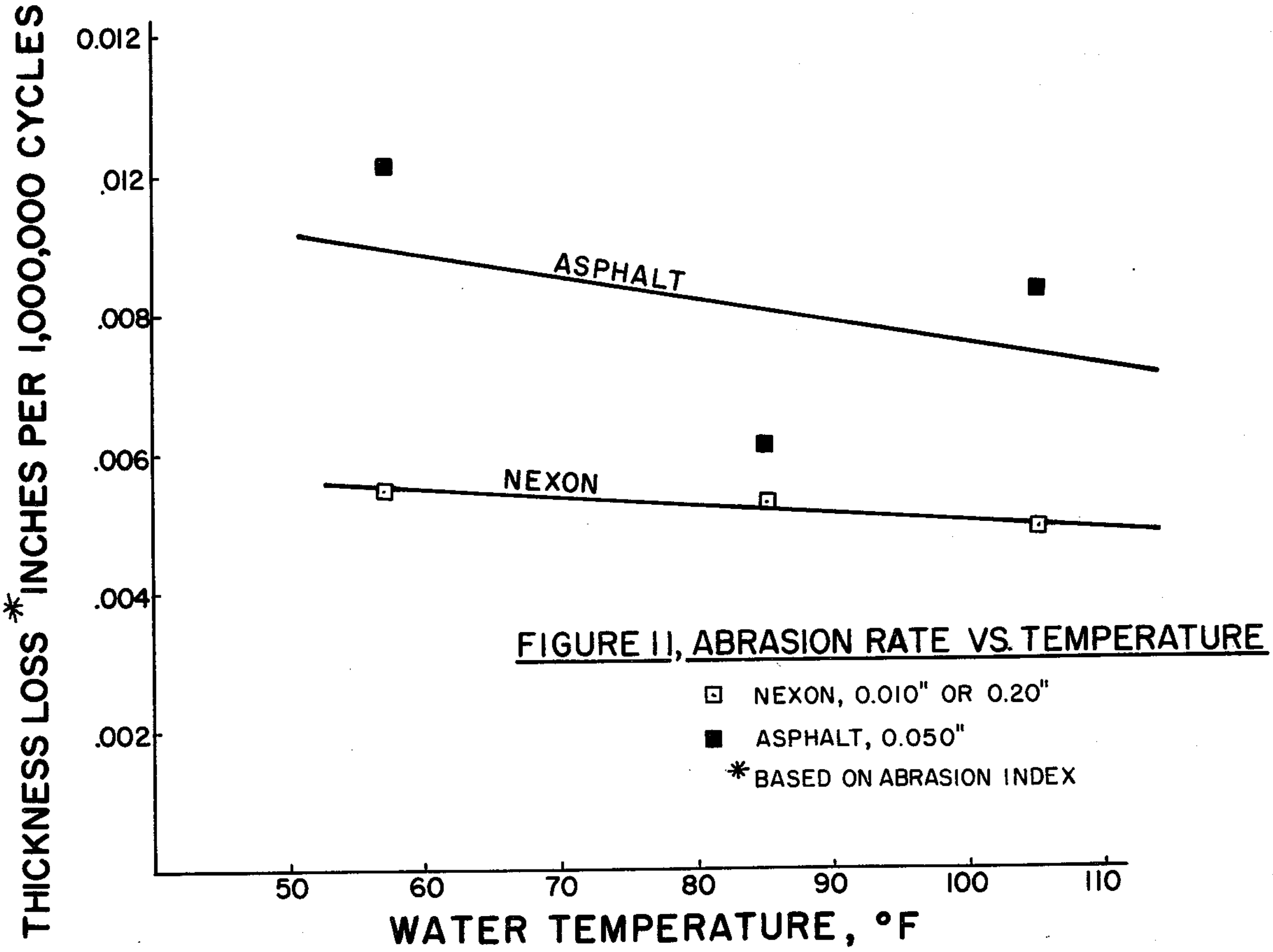
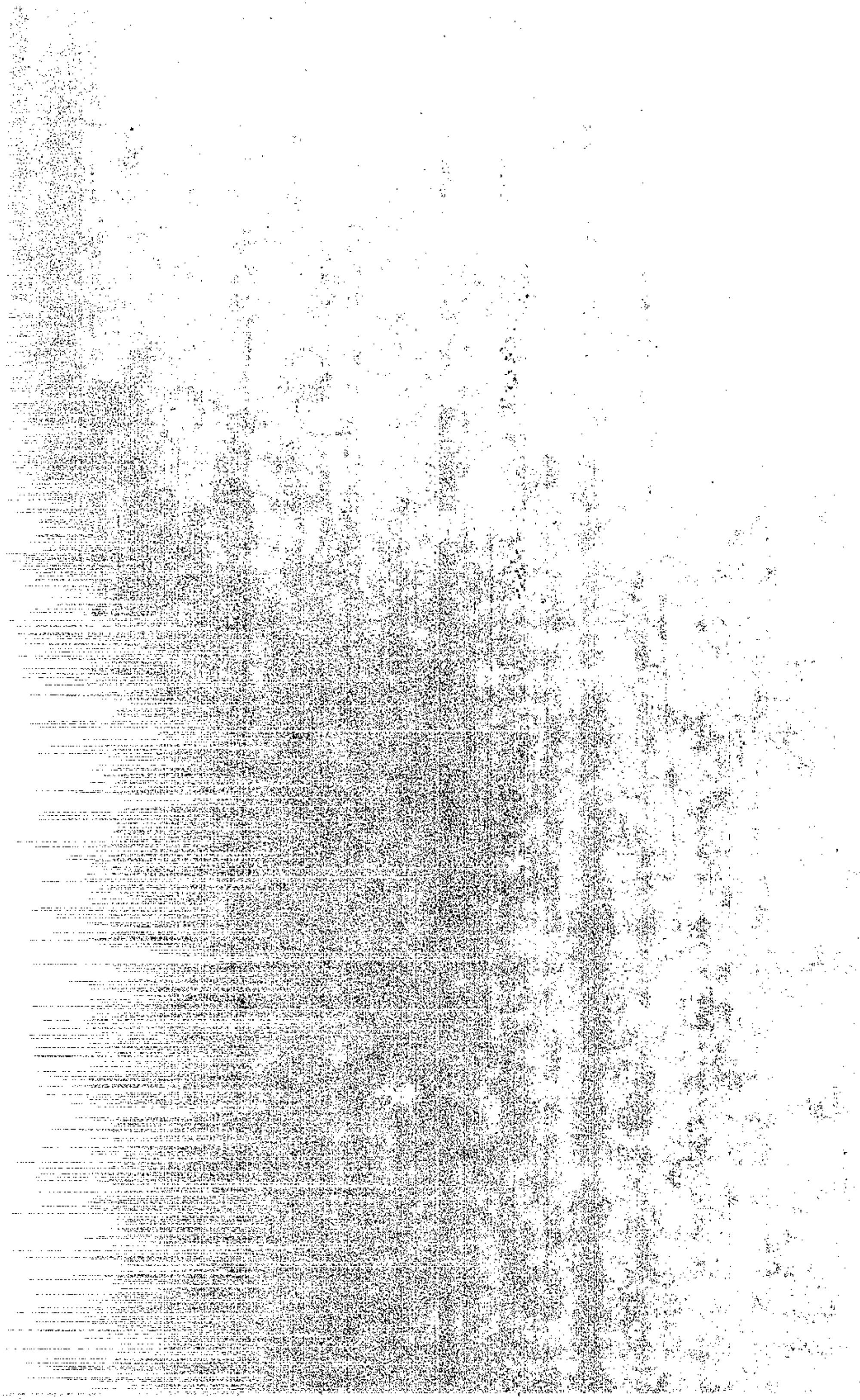


FIGURE 11, ABRASION RATE VS. TEMPERATURE



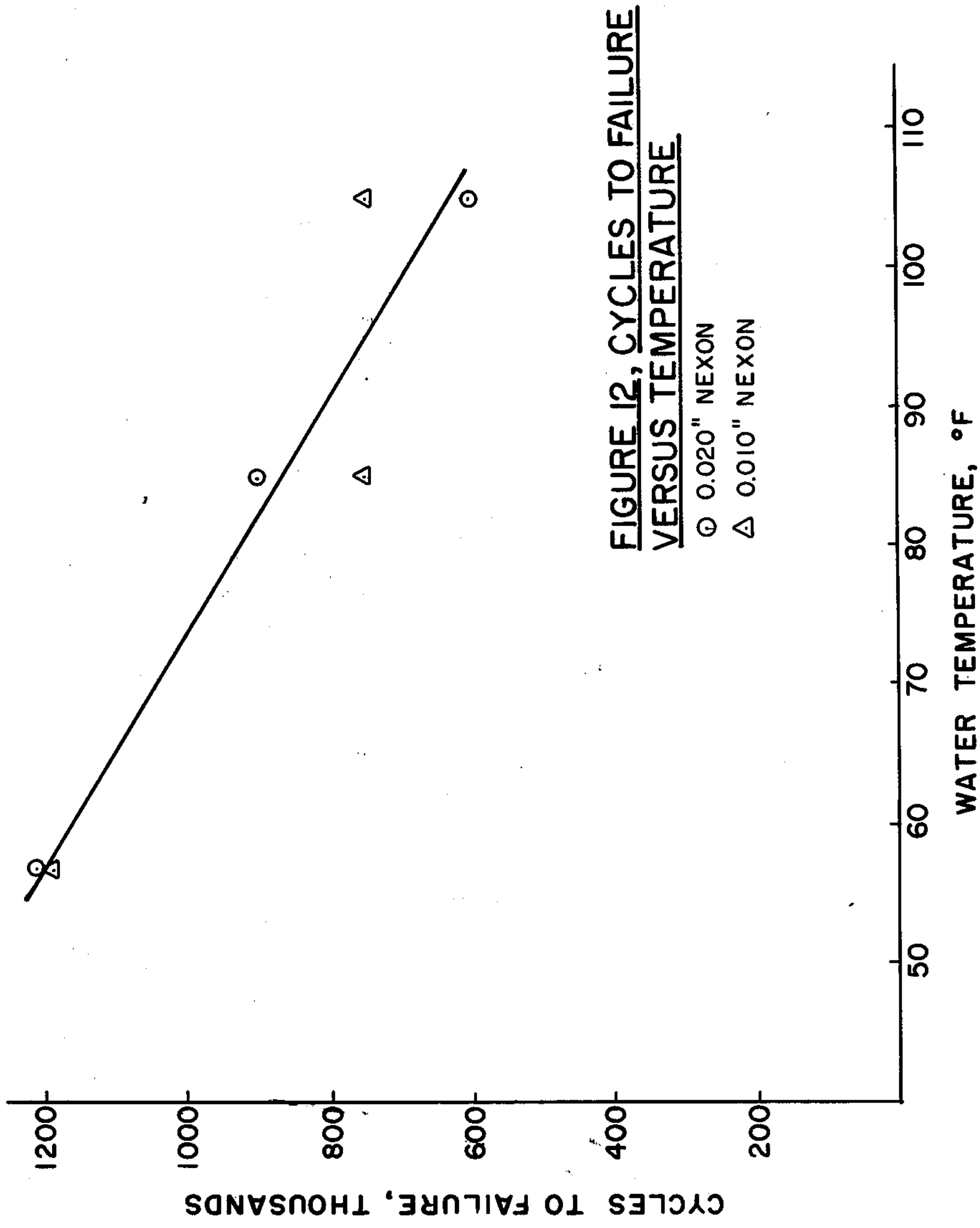
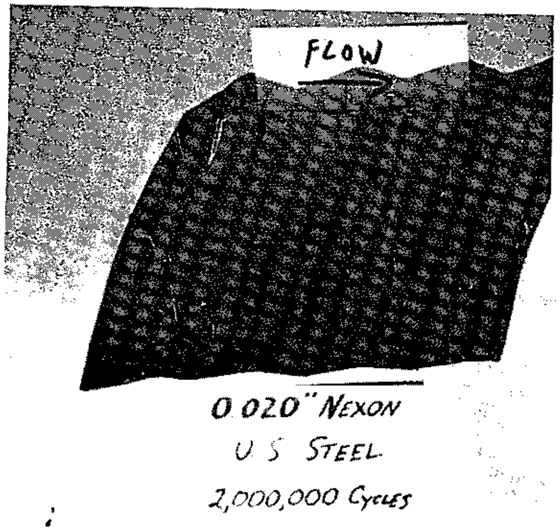
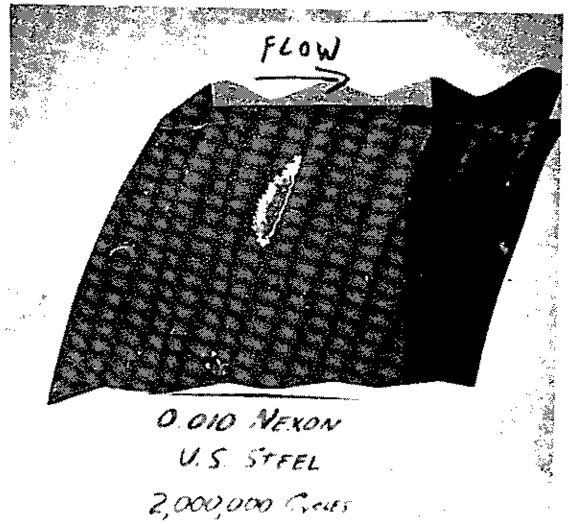


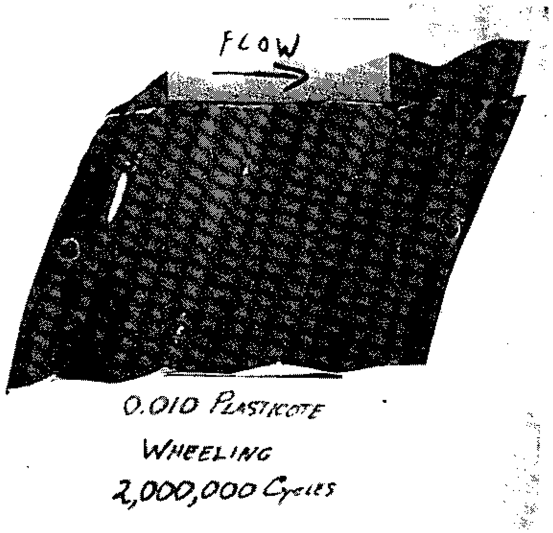
FIGURE 12, CYCLES TO FAILURE VERSUS TEMPERATURE

Based upon a study of the data and test specimens from Runs 5, 6, and 7, it appeared that the failure of the Nexon coatings was caused by not only abrasion but also by water permeating through the Nexon. Therefore, Run 8 was performed at 50°F with no aggregate charge to determine whether or not the Nexon coatings would blister under conditions of non-abrasive flow. After 2,200,000 cycles, there were no signs of blistering which indicates that the presence of fine aggregate in the flow contributes to the blistering.

For Runs 9 and 10 new Nexon samples and the first Plasticote samples were obtained. These samples were checked for compliance with AASHTO M246-76I (Section III.A.), and the two abrasion test runs were intended to compare the ultimate abrasion resistance of the three coating types - Nexon, Plasticote, and asphalt. Figures 13 and 14 show all the polymeric coating specimens after failure, and the single asphalt specimen (No. 24) which was included in both test runs without failure. Failure locations were similar to those witnessed in Runs 5, 6, and 7, but none of the coatings showed any signs of blistering. This lack of blistering tends to confirm the contention of U. S. Steel that sample N-2 was in fact improperly laminated and the abrasion test results of Runs 5, 6, and 7 therefore may not be representative.







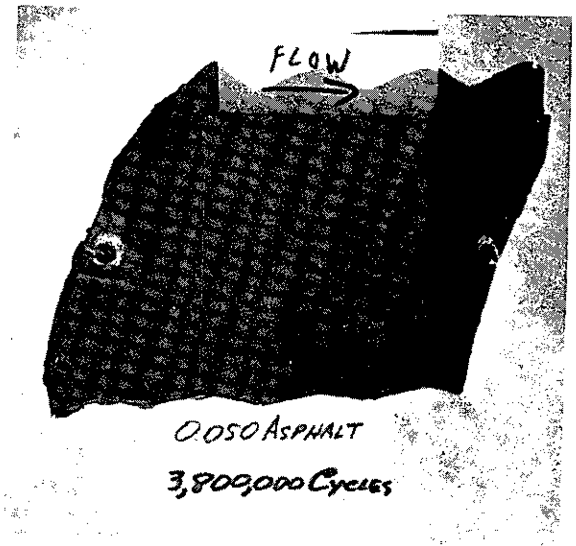
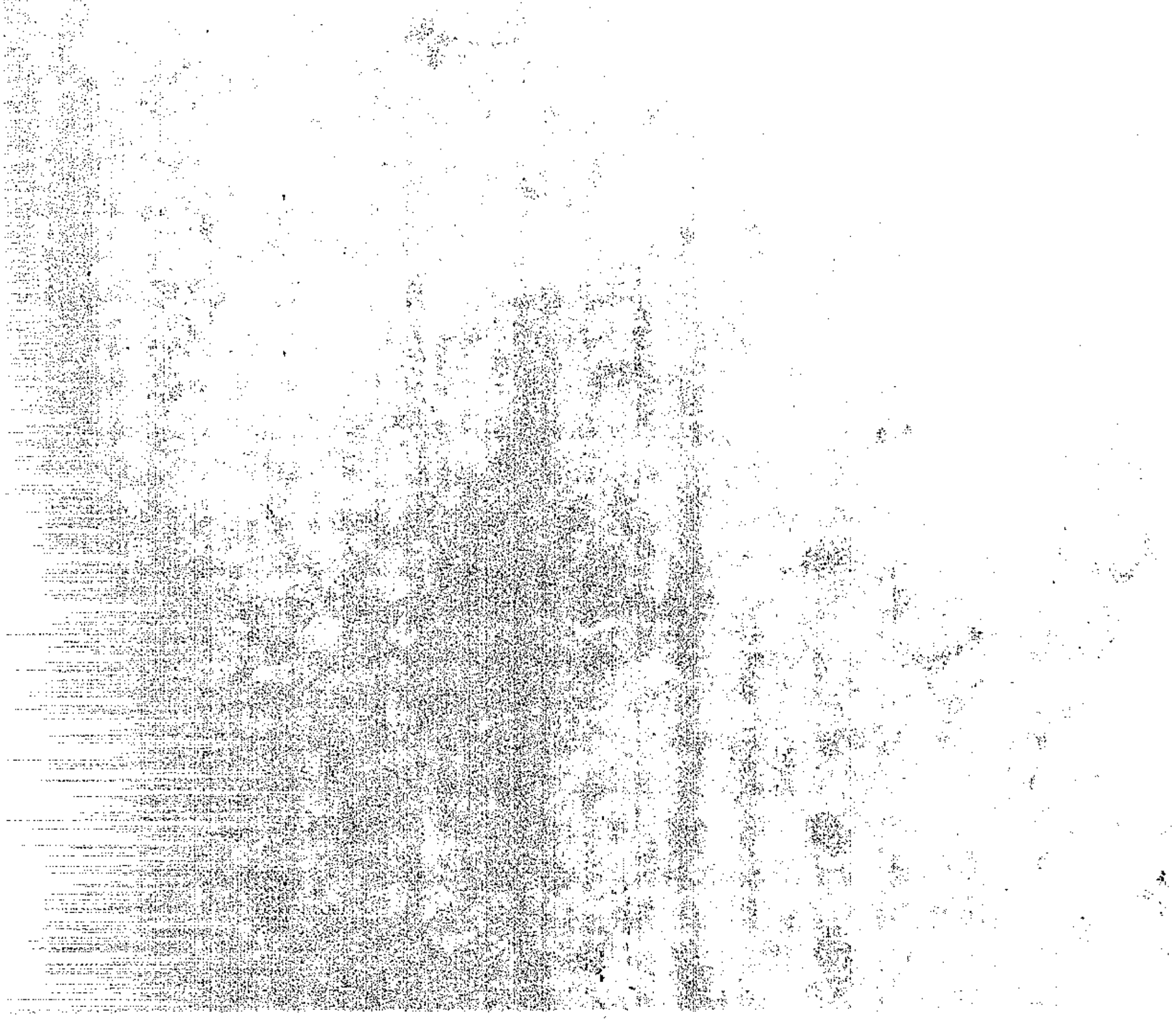


FIGURE 13, SPECIMENS FROM RUN 9



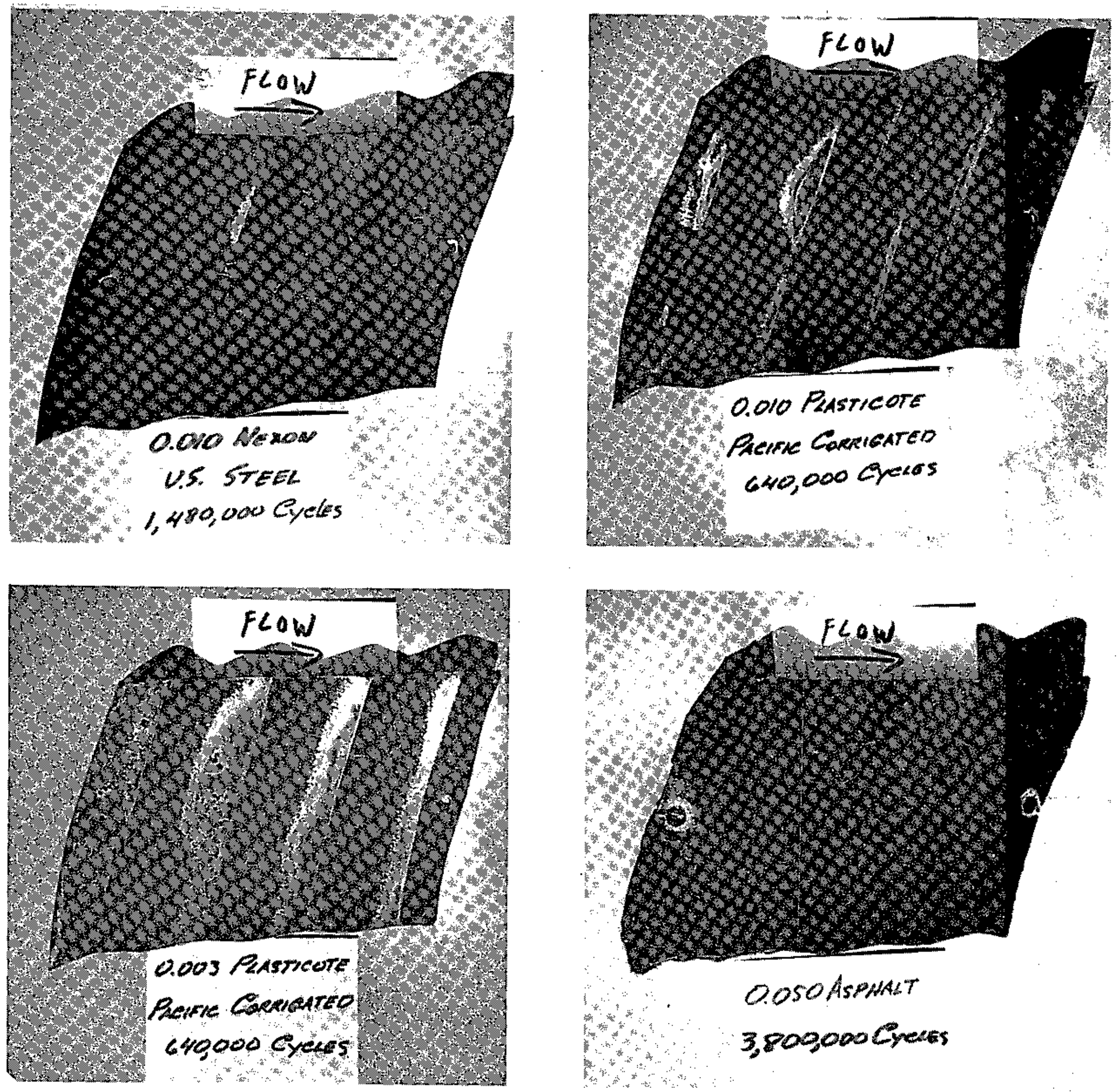


FIGURE 14, SPECIMENS FROM RUN 10

Based upon the final two test runs, the relative abrasion resistance of the coating samples were as follows:

		Cycles to Failure, Millions
1.	0.050 inch asphalt	3.8+
2.	0.020 inch Nexon	2.0
3.	0.010 inch Nexon	2.0, 1.5
	0.010 inch Plasticote (Wheeling)	2.0
4.	0.010 inch Plasticote (Pacific Corrugated)	0.6
5.	0.003 inch Plasticote (Pacific Corrugated)	0.6

Since the asphalt coating showed no signs of failure after 3,800,000 cycles, it is concluded, based on these laboratory tests, that the anticipated lifetime of the asphalt coating is much longer than that of any of the polymeric coatings.

IV. REFERENCES

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